CLAIMS:

1. A method of estimating skew angle in a document image, the method comprising the steps of:

run-length-smoothing the document image (A); and

determining an erosion of the run-length-smoothed image (RLSA) by a linear structuring element (k_2L_α) oriented at each of a plurality of different angles (α), so as to determine the angle at which a surface area of the eroded image is maximum, said angle being designated as the skew angle of the document image.

2. The skew estimation method of claim 1, wherein the step of run-length-smoothing the document image comprises closing the document image using a linear structuring element (k_1L).

3. The skew estimation method of claim 2, wherein:

the step of run-length-smoothing the document image (A) comprises producing a plurality of different run-length-smoothed images ($RLSA_\alpha$), each of said different run-length-smoothed images ($RLSA_\alpha$) being produced by closing the document image (A) using a linear structuring element (k_1L_α) oriented at a respective one (α_i) of said plurality of different angles; and

the step of determining the erosion of the run-length-smoothed image comprises eroding each of said plurality of different run-length-smoothed images ($RLSA_\alpha$) using a linear structuring element (k_2L_α) oriented at the same angle (α_i) as the linear structuring element used in the closing operation producing the respective run-length smoothed image ($RLSA_\alpha$).

4. The skew estimation method of claim 1, wherein the linear structuring element applied in the determining step includes a pair of points ($P_{1,v}$) having a particular angular relationship.

5. The skew estimation method of claim 1, wherein the determining step comprises determining a covariance (K) of the run-length-smoothed image.

6. The skew estimation method of claim 1, wherein the determining step comprises applying a one-dimensional optimization algorithm to determine the angle at which the surface area of the eroded image is a maximum, which reduces the number of angles at which the erosion of the run-length-smoothed image needs to be calculated.

7. The skew estimation method of claim 6, further comprising the step of sub-sampling the document image before applying the one-dimensional optimization algorithm.

8. The skew estimation method of claim 1, wherein when applied to a gray scale document image, a recursive algorithm is used to perform dilation and erosion operations in the run-length-smoothing and determining steps.

9. The skew estimation method of claim 1, wherein when applied to a binary document image, the linear structuring element is decomposed logarithmically, and dilation and/or erosion operations are performed using parallel processing of pixels of the document image.

10. The skew estimation method of claim 1, wherein Fast Fourier Transforms are used to perform dilation and erosion operations in the run-length-smoothing and determining steps.

11. A skew angle estimation apparatus comprising:

run-length-smoothing means adapted to run-length-smooth a document image (A); and

eroding means adapted to determine an erosion of the run-length-smoothed image (RLSA) by a linear structuring element oriented at each of a plurality of different angles, so as to determine the angle at which a surface area of the eroded image is maximum, said angle being designated as a skew angle of the document image.

12. The skew estimation apparatus of claim 11, wherein the run-length-smoothing means is adapted to close the document image using a linear structuring element.

13. The skew estimation apparatus of claim 12, wherein:

the run-length-smoothing means is adapted to produce a plurality of different run-length-smoothed images ($RLSA_\alpha$), each of said different run-length-smoothed images ($RLSA_\alpha$) being produced by closing the document image (A) using a linear structuring element oriented at a respective one (α) of said plurality of different angles; and

the eroding means is adapted to erode each of said plurality of different run-length-smoothed images ($RLSA_\alpha$) using a linear structuring element oriented at the same angle (α) as the linear structuring element used by the run-length-smoothing means in producing the respective run-length smoothed image ($RLSA_\alpha$).

14. The skew estimation apparatus of claim 11, wherein the linear structuring element applied by the eroding means includes a pair of points having a particular angular relationship.

15. The skew estimation apparatus of claim 11, wherein the eroding means comprises means adapted to determine a covariance (K) of the run-length-smoothed image.

16. The skew estimation apparatus of claim 11, wherein the eroding means comprises means applying a one-dimensional optimization algorithm to determine the angle at which the surface area of the eroded image is a maximum, whereby the number of angles at which the erosion of the run-length-smoothed image needs to be calculated is reduced.

17. The skew estimation apparatus of claim 16, further comprising sub-sampling means adapted to sub-sample the document image before the one-dimensional optimization algorithm is applied.

18. The skew estimation apparatus of claim 11, wherein the run-length-smoothing means and eroding means are adapted to use a recursive algorithm to perform dilation and erosion operations when the document image is a gray-scale image.

19. The skew estimation apparatus of claim 11, further comprising parallel processing means for allocating w pixels of the document image to a w-bit data word and applying a dilation and/or erosion operation to the w-bit data word using a bitwise operator

20. The skew estimation apparatus of claim 11, further comprising Fast Fourier Transform units to perform dilation and erosion operations required by the run-length-smoothing means and eroding means.

21. The skew estimation apparatus of claim 11, wherein the apparatus is implemented in a computer.

22. A computer program product embodied on at least one computer-readable medium accessible by a computer, for estimating a skew angle in a document image, the computer program product comprising computer-executable instructions for:

run-length-smoothing the document image (A); and

determining an erosion of the run-length-smoothed image (RLSA) by a linear structuring element (k_2L_α) oriented at each of a plurality of different angles (α), so as to

determine the angle at which a surface area of the eroded image is maximum, said angle being designated as the skew angle of the document image.